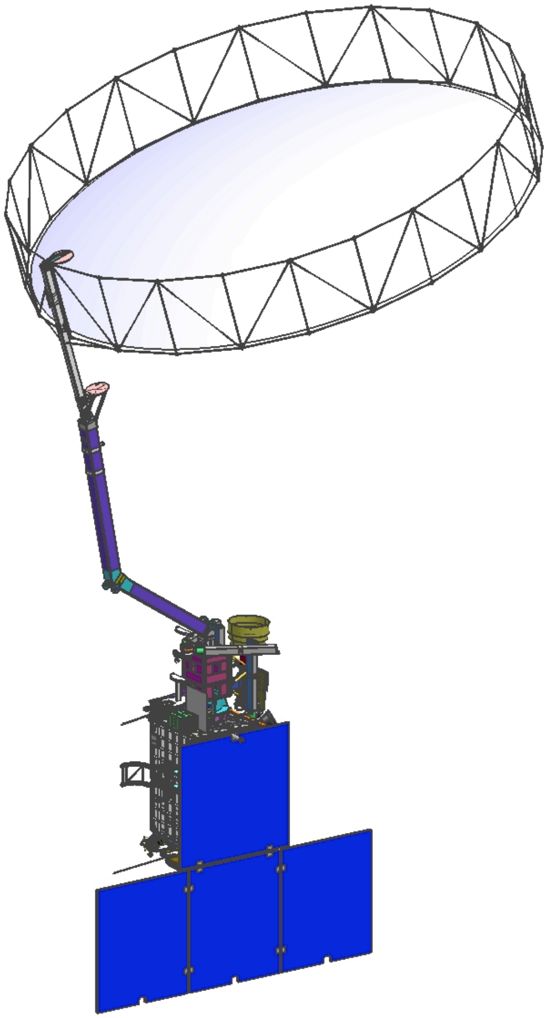

High Resolution Mapping of Soil Moisture with SMAP Radar and Radiometer in Support of new Approaches to Water Cycle Science and Applications

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Kent Kellogg; NASA JPL

July 2009
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Project/Mission Overview—Mission Context

US National Research Council Report: "Earth Science and Applications from Space: National Imperatives for the next Decade and Beyond"

SMAP is one of four missions recommended by the NRC "Decadal Survey" for launch in the 2010–2013 time frame

Tier 1: 2010–2013 Launch	
	Soil Moisture Active Passive (SMAP)
	ICESAT II
	DESDynI
	CLARREO
Tier 2: 2013–2016 Launch	
	SWOT
	HYSPIRI
	ASCENDS
	GEO-CAFE
	ACE
Tier 3: 2016–2020 Launch	
	LIST
	PATH
	GRACE-II
	SCLP
	GACM
	3D-WINDS

- Feb 2008: NASA announces start of SMAP project
- SMAP is a directed-mission with heritage from Hydros
- Hydros risk-reduction performed during Phase A (instrument, spacecraft dynamics, science, ground system) Cancelled 2005 due to NASA budgetary constraints

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Science Requirements

DS Objective	Application	Science Requirement
Weather Forecast	Initialization of Numerical Weather Prediction (NWP)	Hydrometeorology
Climate Prediction	Boundary and Initial Conditions for Seasonal Climate Prediction Models	Hydroclimatology
	Testing Land Surface Models in General Circulation Models	
Drought and Agriculture Monitoring	Seasonal Precipitation Prediction	Hydroclimatology
	Regional Drought Monitoring	
	Crop Outlook	
Flood Forecast Improvements	River Forecast Model Initialization	Hydrometeorology
	Flash Flood Guidance (FFG)	
	NWP Initialization for Precipitation Forecast	
Human Health	Seasonal Heat Stress Outlook	Hydroclimatology
	Near-Term Air Temperature and Heat Stress Forecast	Hydrometeorology
	Disease Vector Seasonal Outlook	Hydroclimatology
	Disease Vector Near-Term Forecast (NWP)	Hydrometeorology
Boreal Carbon	Freeze/Thaw Date	Freeze/Thaw State

Requirement	Hydro-Meteorology	Hydro-Climatology	Carbon Cycle	Baseline Mission	
				Soil Moisture	Freeze/Thaw
Resolution	4–15 km	50–100 km	1–10 km	10 km	3 km
Refresh Rate	2–3 days	3–4 days	2–3 days[1]	3 days	2 days[1]
Accuracy	4–6% **	4–6%**	80–70%*	4%**	80%*

(*) % classification accuracy (binary Freeze/Thaw)
(**) % volumetric water content, 1-sigma

[1]North of 45N latitude

Mission Duration: 3 Years (Launch 2014)

Mission Science Objective

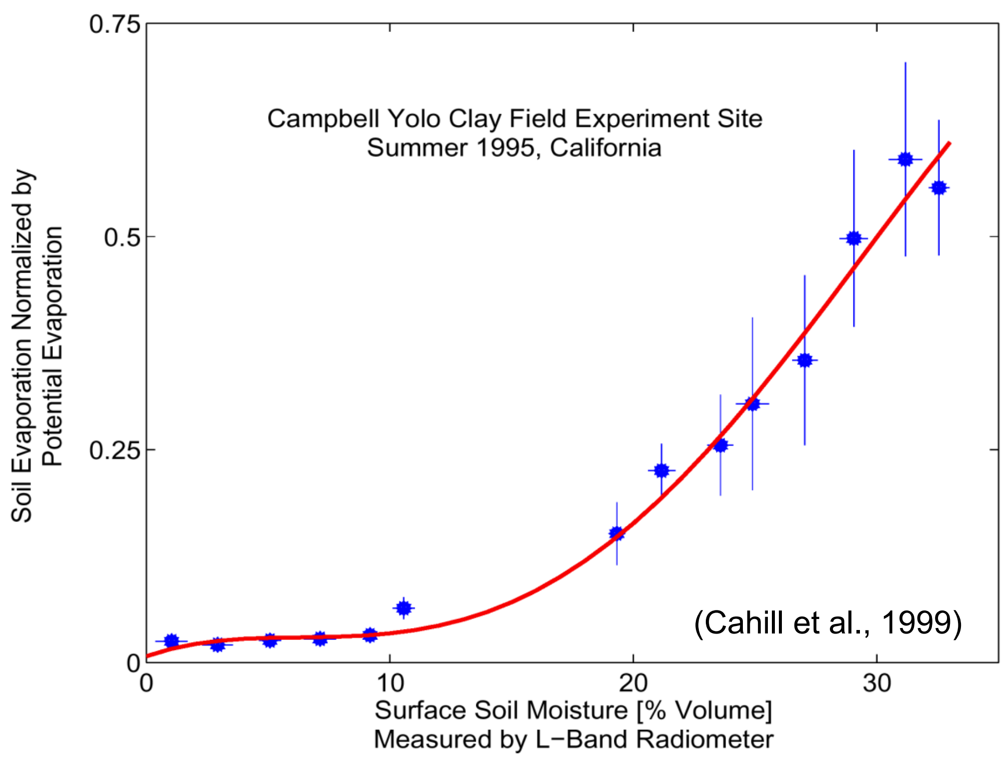
Global mapping of Soil Moisture and Freeze/Thaw state to:

- Understand processes that *link* the terrestrial water, energy & carbon cycles
- Estimate global water and energy fluxes at the land surface
- Quantify net carbon flux in boreal landscapes
- Enhance weather and climate forecast skill
- Develop improved flood prediction and drought monitoring capability

Key Determinants of Land Evaporation

Latent heat flux (evaporation) *links* land water, energy, and carbon fluxes.

Soil moisture exerts control on evaporation:



Lack of knowledge of this relationship and soil moisture determinant causes uncertainty in land surface and atmospheric models.

SMAP surface soil moisture observations would reduce uncertainty in this key relationship globally.

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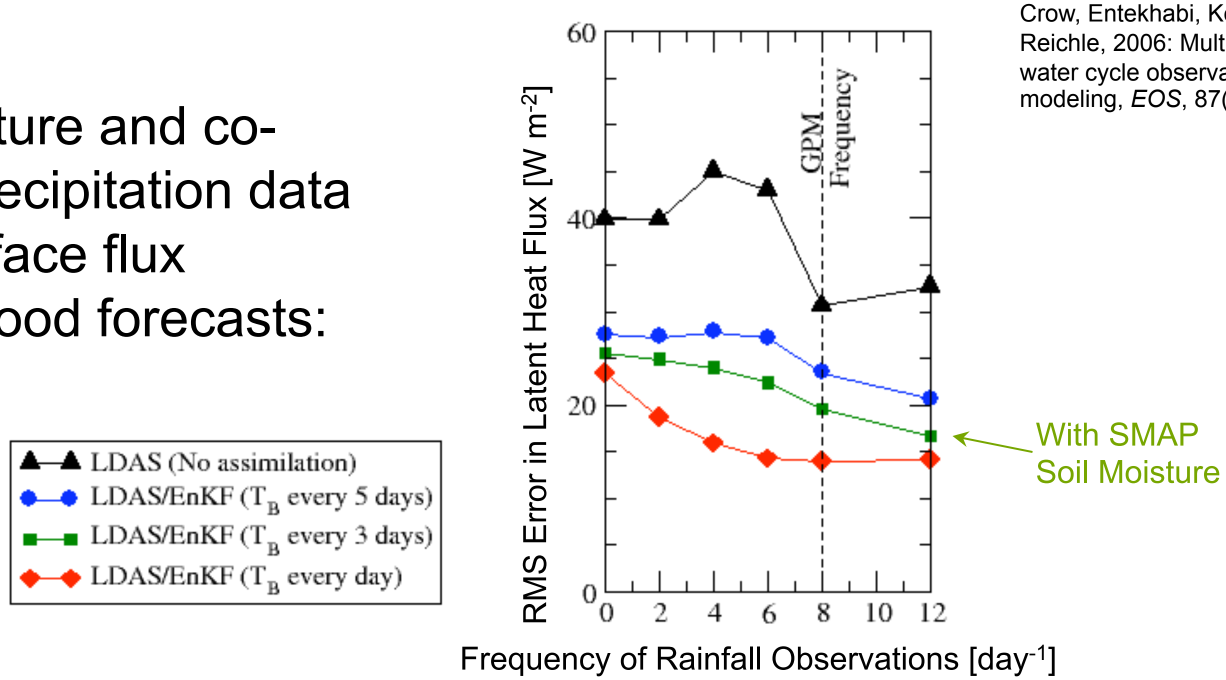
SMAP Synergy With GPM

SMAP and GPM

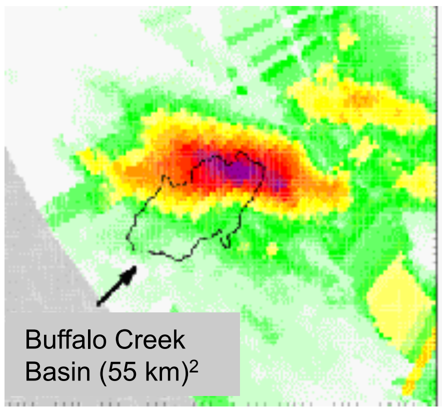
SMAP soil moisture and co-orbiting GPM precipitation data will improve surface flux estimates and flood forecasts:



Crow, Entekhabi, Koster, & Reichle, 2006: Multiple spaceborne water cycle observations would aid modeling, *EOS*, 87(15)

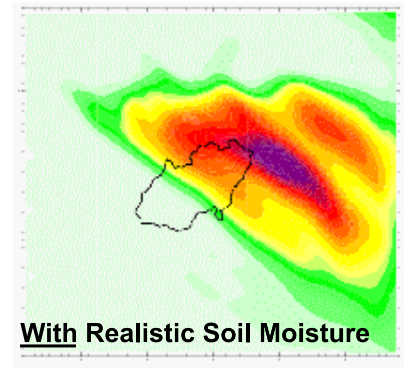
Additionally - With simultaneous SMAP measurements of surface emissivity GPM data can then be used for accurate retrievals of precipitation over land where it is needed for applications

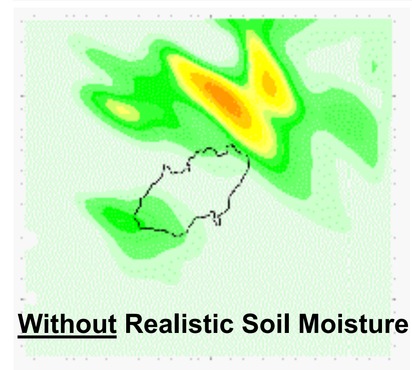
Soil Moisture and Weather Forecasts



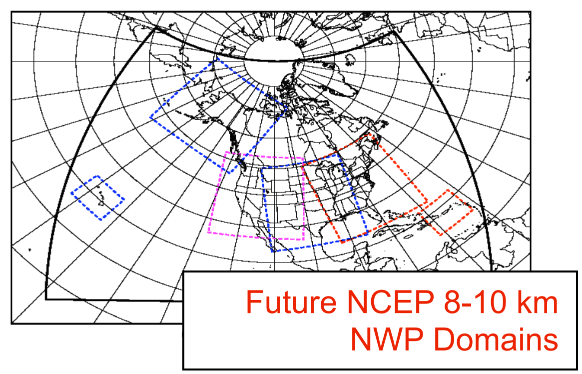
Observed Rainfall
0000Z to 0400Z 13/7/96

24-Hours Ahead Atmospheric Model Forecasts





Chen, F., T.T. Warner, and K. Manning, 2001: Sensitivity of Orographic Moist Convection to Landscape Variability: A Study of the Buffalo Creek, Colorado, Flash Flood Case of 1996. *J. Atmos. Sci.*, 58, 3204–3223.



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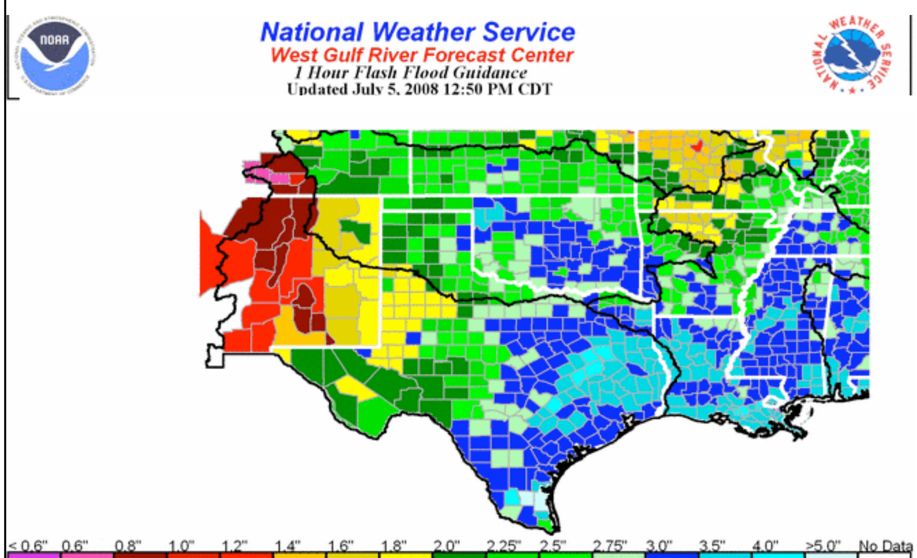
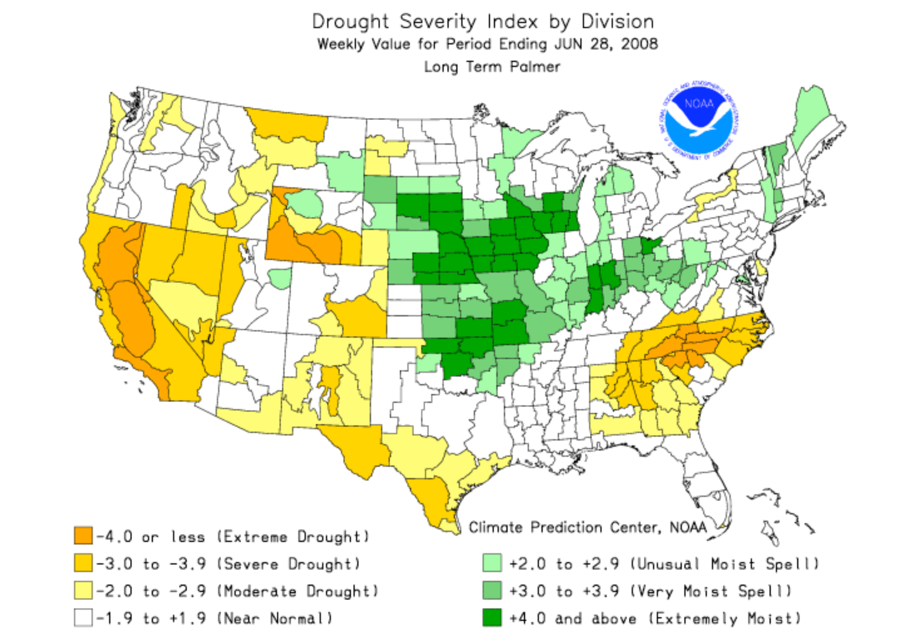
Flood Prediction and Drought Monitoring

Current NWS Operational Flash Flood Guidance (FFG)



Current Operational Drought Indices by NOAA

(NIDIS - National Integrated Drought Information System)



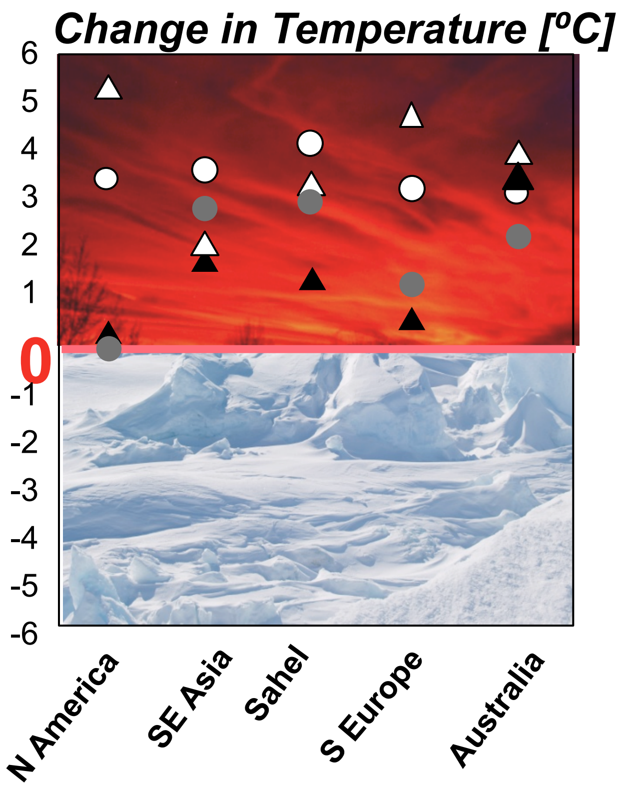
Current: Empirical Soil Moisture Indices Based on Rainfall and Air Temperature
(By Counties >40 km and Climate Divisions >55 km)

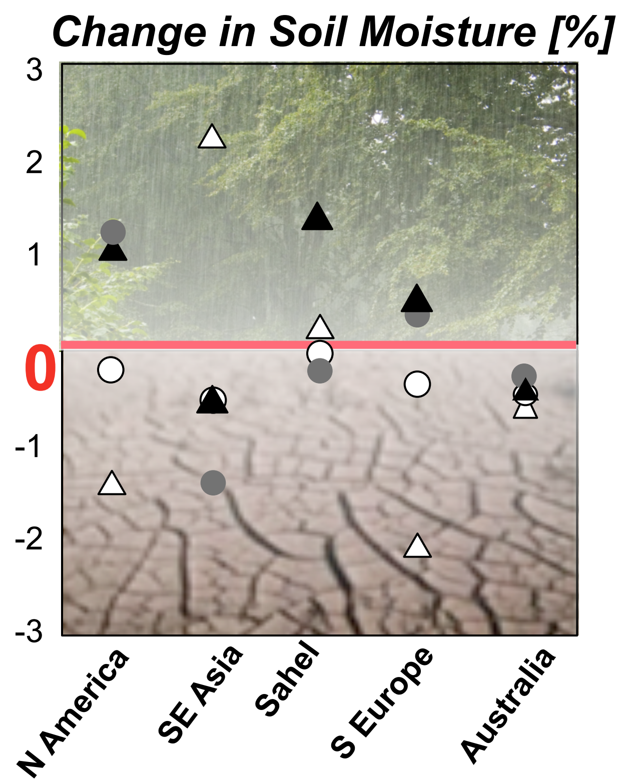
Future: SMAP Soil Moisture Observations at 10 km

Climate Change and Water Resources Impacts

Intergovernmental Panel on Climate Change (IPCC) AR4 climate model projections by region:

Models *agree* on basic temperature response

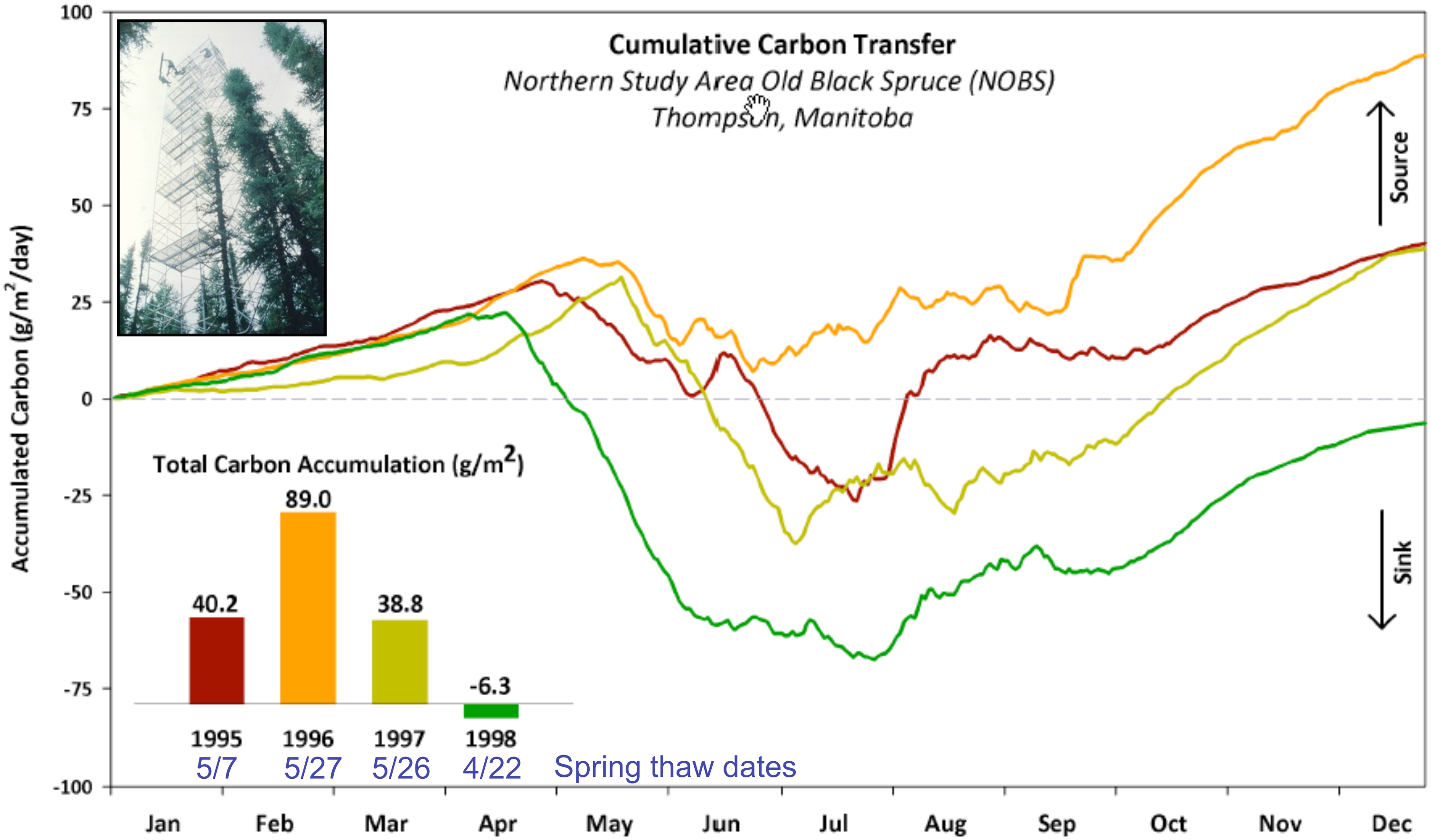




Models *disagree* on whether there would be MORE or LESS water compared to today

Li et al., (2007): Evaluation of IPCC AR4 soil moisture simulations for the second half of the twentieth century, *Journal of Geophysical Research*, 112.

Carbon Dioxide Exchange



Normal to late thaw & Carbon Source [1995, 1996, 1997]

Early thaw & Carbon Sink [1998]

Goulden et al., 1998: Sensitivity of Boreal Forest Carbon Balance to Soil Thaw, *Science*, 279.

Herring, D. and R. Kannenberg: The mystery of the missing carbon, *NASA Earth Observatory*.

The ‘missing carbon’: Depending on freeze/thaw date, same location can be a net source or net sink of carbon.

SMAP freeze/thaw measurements would reduce errors in the closing of carbon budget.

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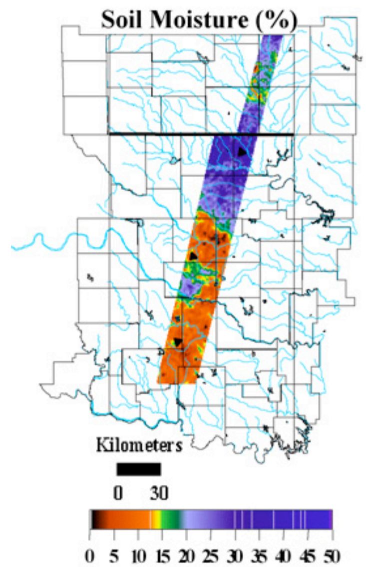
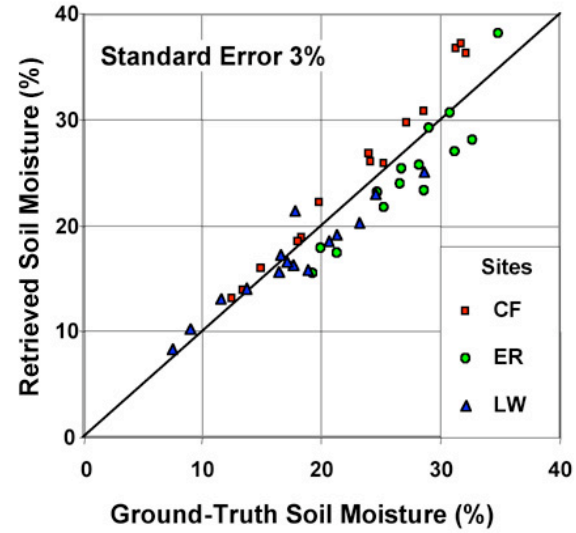
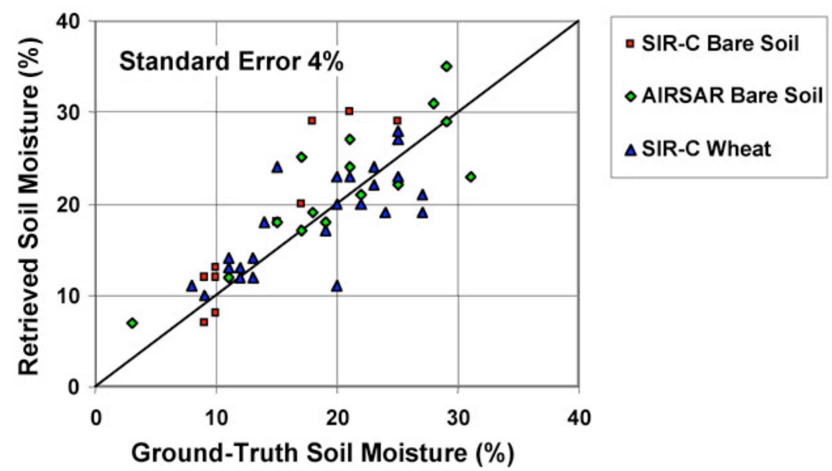
L-band Active/Passive Assessment

- Soil moisture retrieval algorithms are derived from a long heritage of microwave modeling and field experiments
  - MacHydro’90, Monsoon’91, Washita‘92, FIFE, HAPEX, SGP’97,‘99, SMEX’02-‘05
- ***Radiometer*** - High accuracy (less influenced by roughness and vegetation) but coarser spatial resolution (40 km)
- ***Radar*** - High spatial resolution (1-3 km) but more sensitive to surface roughness and vegetation
- **Combined Radar-Radiometer** product provides optimal blend of resolution and accuracy to meet science objectives
- Algorithm approach has been demonstrated in Hydros risk-reduction; OSSE published (Crow et al., 2005); demonstration extended in SMAP Algorithm Testbed





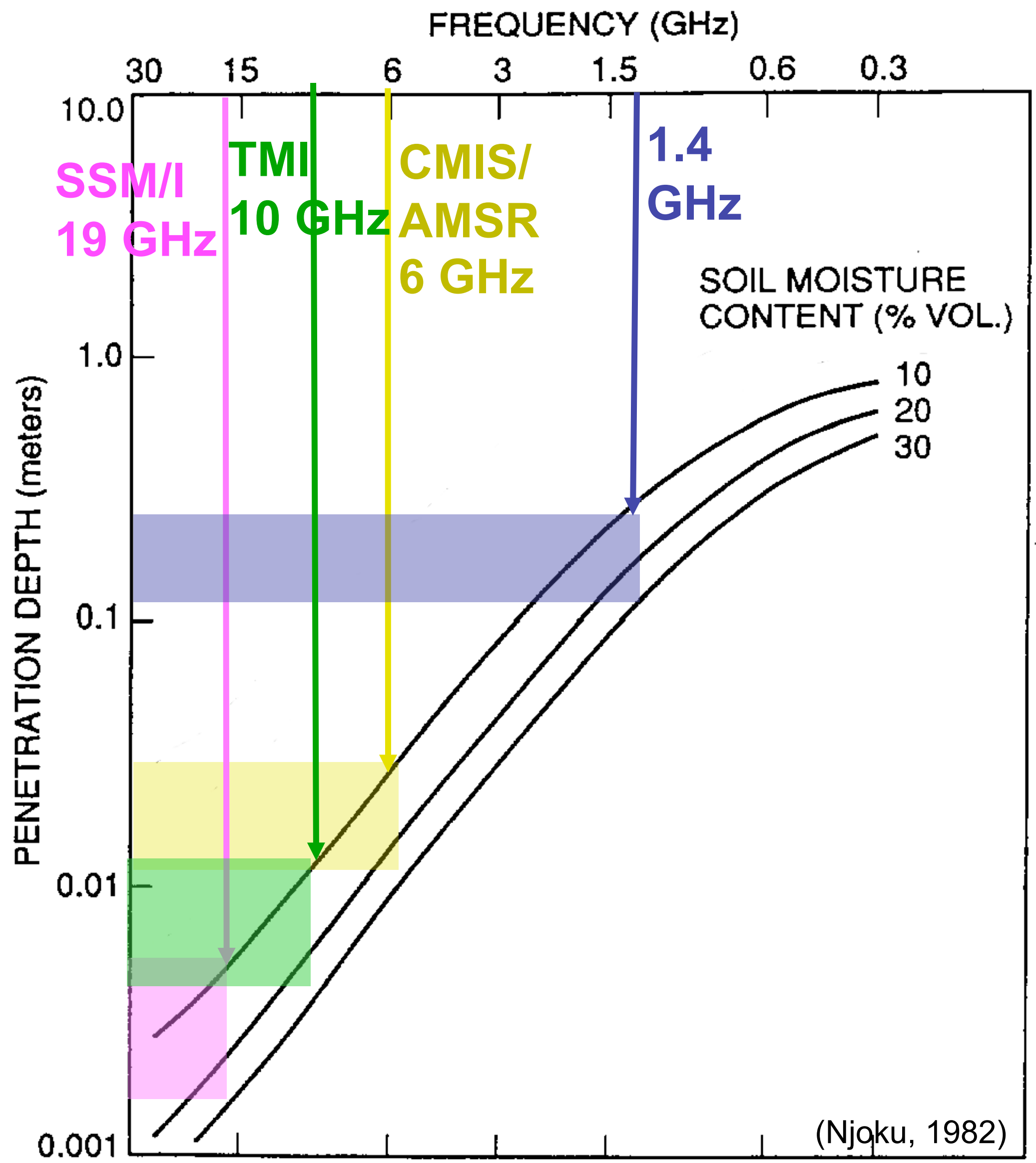


Sensing Depth Across μ-Wave Frequencies

λ = Wavelength
n''=**Im**{Refractive Index}
Power Attenuates as $e^{-z/d}$

$$d = \frac{\lambda}{4 \cdot \pi \cdot n''}$$

Existing Sensors	SSM/I **19 GHz**	Top <1 mm
	TMI **10 GHz**	Top 1 mm
	AMSR/MIS **6 GHz**	Top 1 cm
Future	SMAP **1.4 GHz**	Top 5cm



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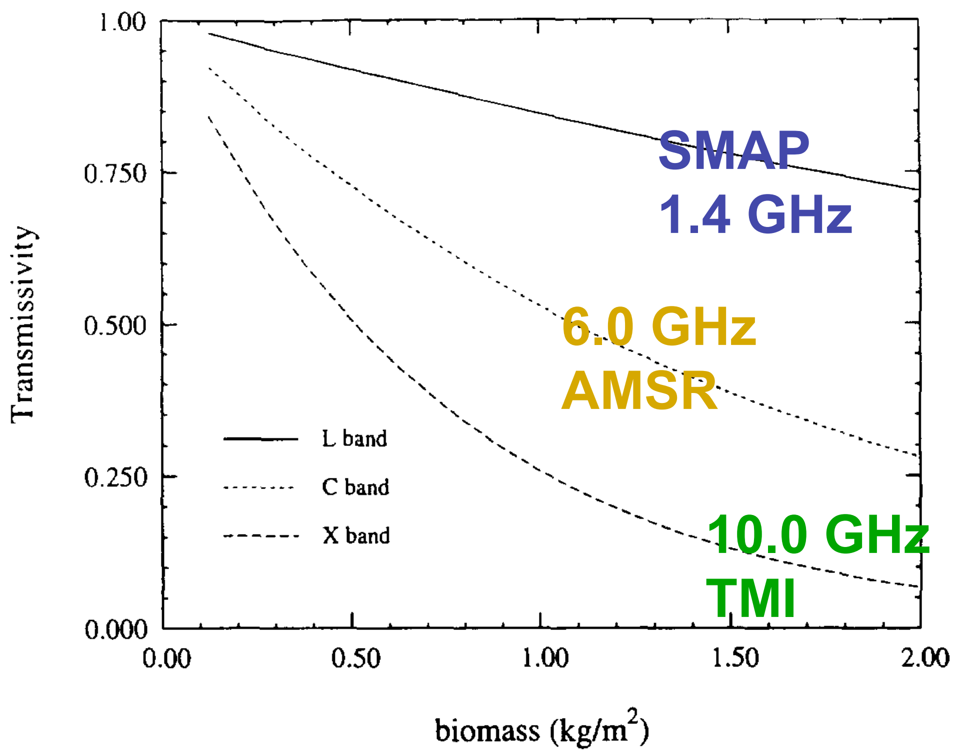
Vegetation Opacity at μ-Wave Frequencies



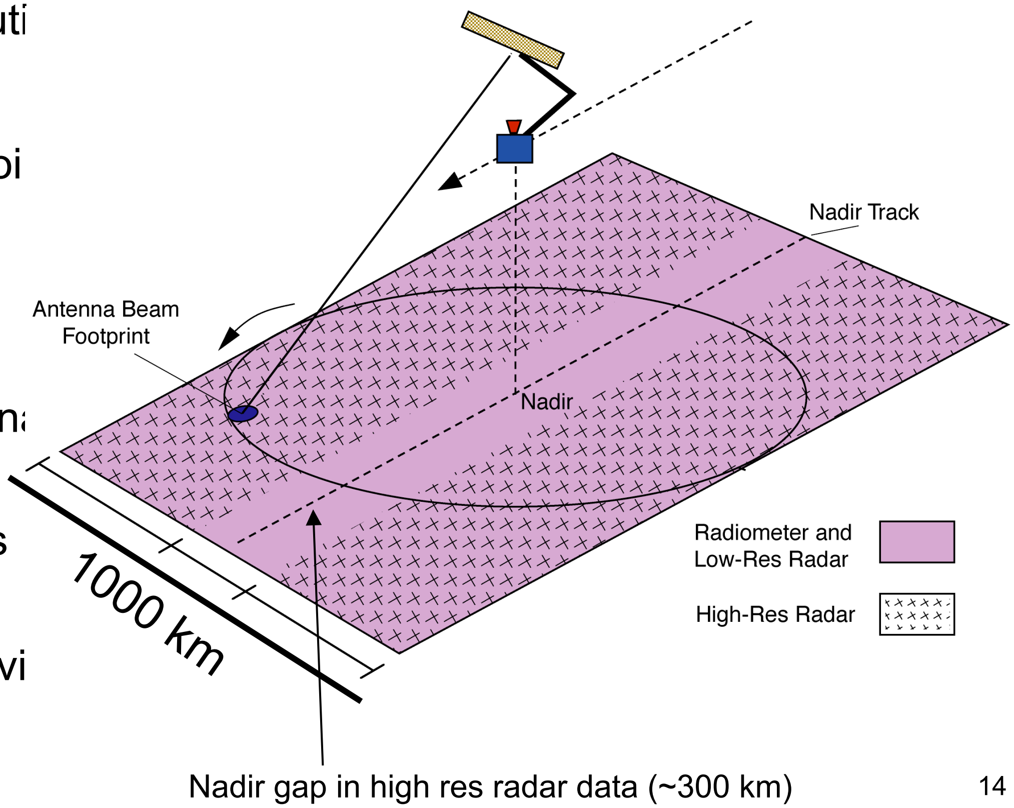
For Example: Signal Loss Over Short Vegetation Cover
100% Lost at 19 GHz (SSM/I)
95% Lost at 10 GHz (TMI)
75% Lost at 6 GHz (MIS/AMSR)
25% Lost at 1.4 GHz (SMAP)

SMAP Measurement Approach

- Instruments:
  - **Radar:** L-band (1.26 GHz)
    - High resolution, moderate accuracy soil moisture
    - Freeze/thaw state detection
    - SAR mode: 3 km resolution
    - Real-aperture mode: 30 x 6 km resoluti
  - **Radiometer:** L-band (1.4 GHz)
    - Moderate resolution, high accuracy soi moisture
    - 40 km resolution
  - **Shared Antenna**
    - 6-m diameter deployable mesh antenn
    - Conical scan at 14.6 rpm
    - Constant incidence angle: 40 degrees
      - 1000 km-wide swath
      - Swath and orbit enable 2-3 day revi

- Orbit:
  - Sun-synchronous, 6 am/pm orbit
  - 670 km altitude

- Mission Operations:
  - 3-year baseline mission (Launch 2014)



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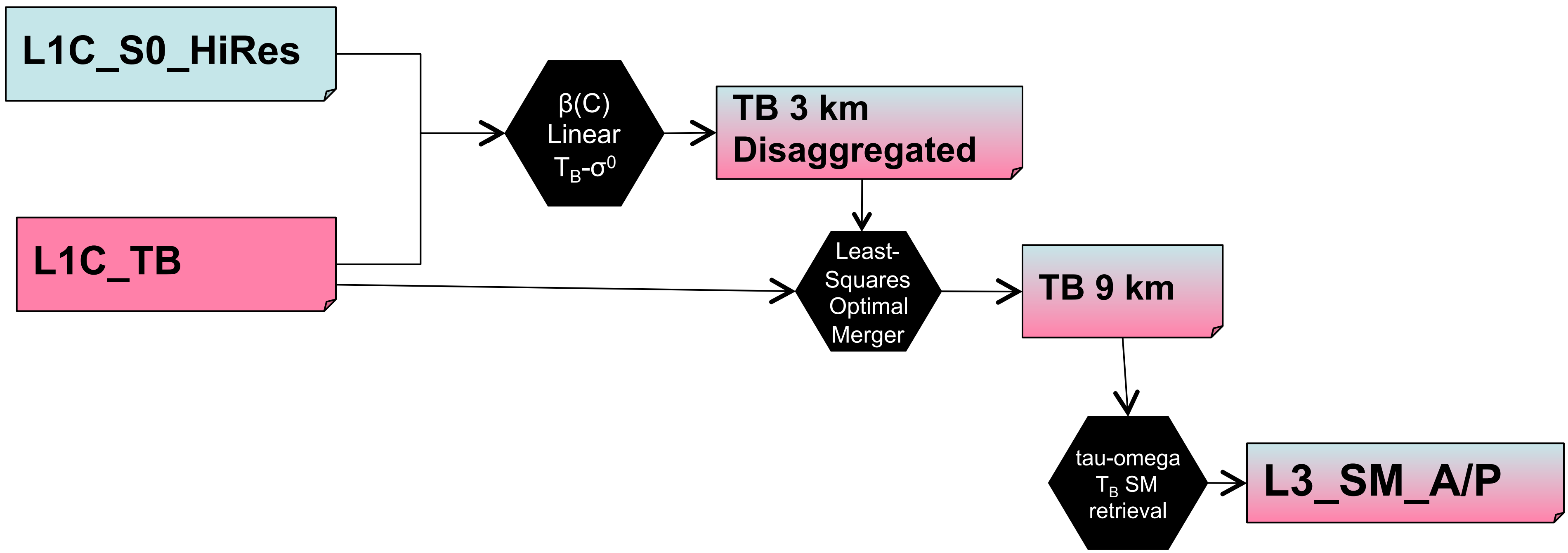
Radar-Radiometer Approach



Advantages:

1. Begins with L1C Instrument Data
2. Uses Same tau-omega Retrieval Code as L3_SM_40km
3. Removes Bias through T_B Aggregation Rule
4. Uses Least-Squares to Beats Down Error
5. Can Use PALS T_B and σ^0 Data to Test (No Ground Sampling Needed)

Disadvantages:

1. Assumes Linear Relation Between T_B and $\log_{10}(\sigma^0)$
2. Linear Coefficient is Vegetation-Dependent and Assume Its Spatial Hetereogeneity is Low Upto 40 km

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SMAP Baseline Science Data Products

Data Product		Spatial Resolution	Nominal Latency	
Short Name	Long Name			
L1B_S0_LoRes	Low Resolution Radar Backscatter (σ^o)	~ 30 km	12 hours	Global Mapping L-Band Radar and Radiometer
L1C_S0_HiRes	High Resolution Radar Backscatter (σ^o)	~ 1 – 3 km	12 hours	
L1B_TB	Radiometer Brightness Temperature (T_B)	~ 40 km	12 hours	
L1C_TB	Radiometer Brightness Temperature (T_B)	~ 40 km	12 hours	
L3_F/T_HiRes	Freeze/Thaw State	~ 3 km	24 hours	High-Resolution and Frequent-Revisit Science Data
L3_SM_HiRes	Radar Soil Moisture (internal product)	~ 3 km	NA	
L3_SM_40km	Radiometer Soil Moisture	~ 40 km	24 hours	
L3_SM_A/P	Radar/Radiometer Soil Moisture	~ 10 km	24 hours	
L4_F/T	Carbon Net Ecosystem Exchange	~ 10 km	14 days	Observations+Model Value Added Product
L4_SM	Surface & Root Zone Soil Moisture	~ 10 km	7 days	

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Summary

1. An Earth Science Mission with

   High Science Returns (Water, Carbon and Energy Cycles)

   High Applications Returns (Operational Hydromet Fx and Drought Monitoring)

2. Design Matured With Hydros Heritage

3. Measurement and Algorithms Matured With Airborne Experiments

4. Mapping L-Band Radar Mapping Data Has Many More Applications

Key Open Science Issues:

- Focused Airborne Experiments on Active/Passive and Freeze/Thaw
- Algorithm Testbed (Testbed to Transition to Science Data System)
- Engagement of Application Users

SMAP Working Groups

Working Groups have been established as a means to enable broad science participation in the SMAP mission. The working groups are led by Science Definition Team (SDT) members and provide forums for information exchange on issues related to SMAP science and applications goals and objectives. The working groups communicate via email and at meetings, conference sessions, workshops, and other venues. There are four current working groups:

1. Algorithms Working Group (AWG)
2. Calibration & Validation Working Group (CVWG)
3. Radio-Frequency Interference Working Group (RFIWG)
4. Applications Working Group (ApWG)

Upcoming Relevant Event

smap.jpl.nasa.gov

SMAP Applications Workshop

September 9-10, 2009

At the NOAA SSMC-3 Building

Silver Spring, MD